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SENSORY, PHYSICAL AND CHEMICAL CHARACTERISTICS OF MEAT FROM FREE-RANGE REARED SWALLOW-BELLY MANGULICA PIGS

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ABSTRACT

Sensory (colour and marbling score), physical (pH, water-holding capacity and $L^*a^*b^*$ values) and chemical (moisture, protein, total fat, total ash, potassium - K, phosphorus - P, sodium - Na, magnesium - Mg, calcium - Ca, zinc - Zn, iron - Fe, copper - Cu and manganese - Mn) characteristics were determined in four (*M. psoas major*, *M. semimembranosus*, *M. longissimus dorsi*, and *M. triceps brachii*) muscles belonging to free-range reared Swallow-belly Mangulica pigs. Muscle had no significant influence (P>0.05) on pH_{30min}, water-holding capacity, b^* value, protein, total ash and K concentration. *M. longissimus dorsi* had significantly (P<0.05) the lightest colour (sensory score, L^* value, a^* value), the lowest moisture concentration, the highest fat concentration and sensory marbling score. The pH_{24h} and Zn concentration were the highest in *M. triceps brachii*. The highest concentration of K, Mg, Fe, Cu and Mn was found in the *M. psoas major*, with significant difference for Fe (P<0.05). In the M. *semimembranosus* significantly the highest (P<0.05) concentration of Na and Ca, and the highest concentration of P were found. Compared to modern pigs, pork from 150 kg live weight, at the age of about 20 months, Swallow-belly Mangulica pigs contained more fat and was darker, while compared to autochthonous pigs determined pork quality were in the characteristic ranges.

Keywords: Pigs; Swallow-Belly Mangulica; Meat; Sensory characteristics; Physical characteristics; Chemical characteristics.

INTRODUCTION

Three Serbian indigenous pig breeds, viz. Mangulica, Moravka and Resavka, are documented in the domestic animal diversity information system (DAD-IS, 2003) of the Food and Agriculture Organization (FAO). The most representative Serbian indigenous pig breed is the Mangulica pig, which is primarily bred in the northern part of the country (Autonomous Province of Vojvodina, located in the Pannonian Plain). Also, there are considerable populations of Mangulica in Hungary, Switzerland, Germany, Austria and some in Romania and in other areas of the former Yugoslavia (Egerszegi *et al.*, 2003). In Serbia, there are three varieties: White (Blond), Swallow-Belly and Red Mangulica (Scherf, 2000; DAD-IS, 2003; Egerszegi *et al.*, 2003).

Today, the Mangulica pig is a representative example of the success of preserving endangered breeds, i.e. Mangulica is one of the last indigenous pig breeds in Europe. This breed is known for maturing late and for its soundness, vitality, resistance and longevity (Scherf, 2000; DAD-IS, 2003; Egerszegi *et al.*, 2003). The Mangulica is one of the fattest pigs in the world, generally 65-70% of the carcass is lard (Scherf, 2000; Egerszegi *et al.*, 2003). The lean meat makes only 30-35% compared to over 50% in modern breeds (Egerszegi *et al.*, 2003). However, there is lack of information about pork quality from free-range reared Swallow-Belly Mangulica pigs from Vojvodina (northern Serbia).

Nowadays, there is increasing interest by consumers for food from organic agriculture systems, i.e. for meat and meat products from free-range rearing pig production systems (Cava *et al.*, 2003). Also, crossings between modern and traditional pig breeds may be used for production of new unique gourmet pork products (Coutron-Gambotti *et al.*, 1999; Galián *et al.*, 2007; Poto *et al.*, 2007). In the last few years, the population of free-range reared Serbia's Mangulica pigs has continuously being increasing in all colour types, although the number of Swallow-Belly and Red Mangulica is still critically low (DAD-IS, 2003).

Traditionally, meat from autochthonous, as well as Mangulica, pigs has been processed into unique highly-priced dry-cured meat products: dry-hams, loins, and sausages (Cava *et al.*, 2003; Galián *et al.*, 2007). Most of these products still rely primarily on local, traditional manufacturing processes.

Sensory (colour, marbling, odour, flavor, juiciness, consistency, tenderness), technological (pH value, water-holding capacity, colour, tenderness, protein content and its status, fat content and its status, connective tissue content) and nutritional (proteins and amino acids composition, fats and fatty acids composition, minerals, vitamins, biological value, utilization and digestibility) meat quality traits may be influenced by multiple interacting factors before and after slaughter. These include breed, sex, genotype, feeding, production systems, pre-slaughter handling, stunning method, slaughter procedure, chilling and storage conditions (Rosenvold and Andersen, 2000; Olsson and Pickova, 2005).

The genetic influence on pork quality comprises differences among breeds as well as differences among animals within the same breed. These differences can be caused by a large number of genes with small effects, known as polygenic effects, and in principle most traits of interest for meat quality have a multifactorial background (Andersson, 2001). However, pork quality attributes can also be associated with large monogenic effects. Such genes are known as major genes (Sellier and Monin, 1994). When major gene effects are excluded, genetics explain around 30% of the variation in meat quality traits (Olsson and Pickova, 2005).

The aim of this study was to determine the sensory, physical and chemical characteristics of four major muscles (*M. psoas major*, *M. semimembranosus*, *M. longissimus dorsi*, and *M. triceps brachii*) from free-range reared Swallow-Belly Mangulica pigs and to compare their characteristics with meat from lean and autochthonous pigs reported in the literature. This is important to provide, update and improve regularly nutrient composition data of pork meat.

MATERIALS AND METHODS

Animals, diet, slaughter procedure, sampling and preparing: This study was carried out on 15 male purebred Swallow-Belly Mangulica pigs randomly selected over a 2-year period. All pigs were castrated under anesthesia after weaning. The Swallow-Belly Mangulica pigs were free-range reared on the territory of natural protected area "Zasavica", Sremska Mitrovica, Autonomous Province of Vojvodina (northern Serbia) (DAD-IS, 2003; Jokanović *et al.*, 2013).

The growth and development of Swallow-Belly Mangulica pig included different periods. During the first period (lactation and weaning) the piglets were nursed by the sow from birth to weaning, which lasted 50 days (7-8 kg). In the period of 10-50 days of age the piglets also had *ad libitum* access to mixed diet containing maize (80%) and wheat, oat and barley (20%). From weaning to 90 days of age (13-15 kg), the piglets were fattened on the same mixed diet. The free-range pigs were then allowed to roam in pasture and oak groves, to feed naturally on grass, herbs, acorns, and roots, until the slaughtering time approached.

The pigs were slaughtered at the weight of 147.0±5.4 kg (which is considered an optimum slaughtering weight for Swallow-Belly Mangulica pork quality, as well as other indigenous pigs; Scherf, 2000; DAD-IS, 2003), at the age of about 604±14 days, in commercial slaughterhouse according to the routine procedure (Tomović *et al.*, 2013 b). The carcasses were divided into two sides, inspected and passed by the government officers, and after the washing and trimming processes conventionally chilled overnight in a chiller at 2-4 °C. Dorsal mean fat thickness, measured by ruler on the carcass split line over the *M. gluteus medius*, was 52.2 mm. The right side of each carcass was then transferred to the meat laboratory of University of Novi Sad, Faculty of Technology.

The following 4 muscles were excised from the right side of each carcass: *M. psoas major* (PM), *M. semimembranosus* (SM), *M. longissimus dorsi* (LD), and *M. triceps brachii* (TB). The meat samples were trimmed of visible adipose and connective tissue. Sensory and physical characteristics were measured on fresh muscles. After determination of sensory and physical characteristics each muscle was homogenized (Waring 8010 ES Blender, USA; 1 l - capacity, 18000 rpm - speed, 10 s - duration of homogenization, <10 °C - temperature after homogenization), vacuum-packaged in plastic bags and stored at –40 °C until determination of proximate and mineral composition.

Meat quality measurements. Sensory analysis: Eight (four male and four female) selected and trained panelists (ISO 8586-1, 1993; ISO 8586-2, 2008) evaluated pork colour and marbling scores using sets of National Pork Producers Council (NPPC, 2000) official colour and marbling standards. Samples for colour and marbling evaluation were taken from the central part of each muscle (three chops), perpendicularly to the long axis of muscle; the minimum thickness of samples was 2.5 cm. Colour was evaluated, for each chop, by the panelists with NPPC (2000) 6-point color score cards (1=pale pinkish-gray to white, 2=grayish-pink, 3=reddish-pink, 4=dark reddish-pink, 5=purplish-red, 6=dark purplish-red). Marbling was evaluated, for each chop, by the panelists with NPPC (2000) 7-point marbling score cards.

Physical measurements: The pH value was measured in the center of each muscle at 30 min (pH_{30min}) and 24 h (pH_{24h}) *post-mortem* using the portable pH meter (Consort T651, Turnhout, Belgium) equipped with an insertion glass combination electrode (Mettler Toledo Greifensee, Switzerland) (ISO 2917, 1999; Tomović *et al.*, 2013 b). The pH meter was calibrated after each muscle using standard phosphate buffers (pH value of calibration buffers was 7.02 and 4.00 at 20 °C). Measurements were performed in triplicate.

Determination of the water-holding capacity (WHC) was based on measuring water (exudative juice) liberated when pressure was applied to the muscle tissue. Exudative juice was assessed using a filter paper press method (Grau and Hamm, 1953). A cube of 300±25 mg of meat from the inside of the muscle sample was placed on a filter paper (Schleicher & Schull No. 2040 B, Dassel, Germany) between two plexiglas plates, then plates were screwed together tightly for exactly 5 min. The analysis was performed in triplicate. The difference between the areas (RZ), as determined by mechanical polar planimeter (REISS Precision 3005, Bad Liebenwerda, Germany), of the pressed meat film (M) and the wet area on the filter paper (T) is a measure of the exudative juice or WHC. Alternatively, the WHC was expressed as the ratio of M over RZ and the ratio of M over T.

Four replicate surface colour measurements were performed on the same chops prepared for sensory analysis, after 60 min of blooming at 3 °C (Honikel, 1998). The L^* (lightness), a^* (redness) and b^* (yellowness) colour coordinates of International Commission on Illumination (CIE, 1976) were determined using KONIKA MINOLTA Chroma Meter CR-400 (Minolta Co., Ltd., Osaka, Japan) under condition described by Tomović *et al.* (2008).

Proximate composition: Moisture (ISO, 1442, 1997), protein (nitrogen x 6.25; ISO 937, 1978), total fat (ISO 1443, 1973) and total ash (ISO 936, 1998) concentrations of muscle were determined according to methods recommended by International Organization for Standardization. All analyses were performed in duplicate.

Mineral composition: The total phosphorous (P) of muscle was determined according to ISO method (ISO 13730, 1996). The metals (potassium - K, sodium - Na, magnesium - Mg, calcium - Ca, zinc - Zn, iron - Fe, copper - Cu and manganese - Mn) of the meat were determined after dry ashing mineralization as described in detail in Jokanović *et al.* (2013) and in Tomović *et al.* (2011 a, b, c, 2013 a). All analyses were performed in duplicate.

Quality control: A strict analytical quality control programme was applied during the study. The results of the analytical quality control programme for proximate composition are presented in Table 1, while the results of the analytical quality control programme for mineral composition were presented in detail in Jokanović *et al.* (2013) and in Tomović *et al.* (2011 a, b, c, 2013 a).

Statistical analysis: All data are presented as arithmetic mean, standard deviation (SD) and range. Data were analysed statistically with one way ANOVA and post-hoc test (Duncan's test). Levels of significance P<0.05 and P<0.01 were used. Correlation coefficients were also calculated. Statistical analysis was conducted using Statistica software version 10 (StatSoft Inc., 2011).

RESULTS AND DISCUSSION

Sensory characteristics: Results for sensory characteristics (colour and marbling) of all four muscles (PM, SM, LD and TB) of Swallow-Belly Mangulica pigs are presented in Table 2. The LD muscles had the significantly (P<0.05) lowest visual color score (the lightest colour) of all four muscles. However, each individual muscle had visual color score higher than 3 (darker than reddish pink), according to NPPC (2000) standard. On the contrary, among all four muscles visual marbling scores were significantly (P<0.05) the highest in the LD muscles. As expected, in the present study (Table 6) the visual colour score decreased with increasing visual marbling score, i.e. visual colour was significantly (P<0.05) negatively correlated with visual marbling (r=–0.53).

Physical characteristics: Results for physical characteristics (pH value, WHC and instrumental colour – $L^*a^*b^*$ values) of all four muscles (PM, SM, LD and TB) of Swallow-Belly Mangulica pigs are presented in Table 3. There were no differences (P>0.05) in pH value, at 30 min *post-mortem*, among all four muscles. The mean pH_{30min} value was from 6.22 (SM) to 6.34 (TB). Each individual pH_{30min} value, in all four muscles, was between 6.02 (PM) and 6.67 (LD). These initial pH values were consistent with normal pH values of good pork quality (Honikel, 1999). Also, results for pH_{30min} obtained in the present study are in agreement with investigations performed on autochthonous pigs by Poto *et al.* (2007), Galián *et al.* (2009), Peinado *et al.* (2004) and Pugliese *et al.* (Pugliese *et al.*, 2005).

The rate of *post-mortem* pH fall is an important determinant of water-holding capacity and colour. An abnormally rapid rate of *post-mortem* glycolysis (initial pH<6.0) in the muscles produces poor pork quality (pale, soft and exudative (PSE) meat) (Fujii *et al.*, 1991; Huff-Lonergan and Lonergan, 2005).

At 24 h *post-mortem* TB muscles had significantly higher pH than SM (5.72 : 5.55; P<0.01) and LD (5.72 : 5.46; P<0.01) muscles, while PM muscles had significantly higher pH than LD (5.63 : 5.46; P<0.01) muscles (Table 3). However, each individual ultimate pH value, in all four muscles, was within the characteristic range for pork (Honikel, 1999), i.e. lower than 6.0 what indicated high pork quality (Warner *et al.*, 1997; Joo *et al.*, 1999). Also, results for pH_{24h} obtained in the present study are in agreement with investigations performed on autochthonous pigs by Poto *et al.* (2007), Galián *et al.* (2009), Peinado *et al.* (2004) and Pugliese *et al.* (2004, 2005).

WHC, i.e. M, RZ, M/RZ and M/T, did not differ significantly (P>0.05) among all four muscles (Table 3). All four different expressions for the filter paper press method indicated good pork WHC (a bigger M/T ratio indicating a better WHC) (Hofmann *et al.*, 1982).

Same as in the case of sensory evaluation of color, instrumental colour measurements for lightness (L^* value) and redness (a^* value) were significantly affected by muscles (Table 3). The LD muscles had significantly (P<0.05) higher L^* value (higher L^* value indicates lighter color) and lower a^* value than other three muscles. According to criteria for pork colour (L^* value), except LD muscles, all three other muscles had darker mean colour than reddish-pink (L^*<42) (Warner *et al.*, 1997; Joo *et al.*, 1999; Tomović *et al.*, 2008; Tomović *et al.*, 2013 b). Also, the LD muscles had mean L^* value significantly lower than 53, what is the highest acceptable L^* values for LD muscle (Warner *et al.*, 1997; Honikel, 1999; Joo *et al.*, 1999; Tomović *et al.*, 2008; Tomović *et al.*, 2013 b).

Most of the striking differences in the colour of meat surface arise from the chemical state of the myoglobin molecules. It is clear that a high level of muscular activity (free-range rearing) evokes the elaboration of more myoglobin – reflecting, in this respect, differences due to species, breed, sex, age, type of muscle and training. With age the great increase in myoglobin concentration is evident (Lawrie, 1950; Mancini and Hunt, 2005). Thus, according to the visual evaluations of colour and instrumental colour measurements it could be stated that one prominent characteristic of Swallow-Belly Mangulica muscles analyzed in the present study is darker colour. These results are in agreement with results reported for *M. longissimus dorsi* by Cava *et al.* (2003) and Estévez *et al.* (2003) for Iberian pigs, Galián *et al.* (2007, 2009), Poto *et al.* (2007) and Peinado *et al.* (2004) for Chuto Murciano pigs, and Pugliese *et al.* (2004, 2005) for Cinta Senese and Nero Siciliano pigs. Furthermore, the PM muscles were significantly (P<0.01) the reddest (highest a^* value) comparing to other three muscles. For yellowness (b^* value), no significant (P>0.05) differences were detected among all four muscles.

Higher pH is associated with better WHC and darker color. The high ultimate pH alters the light absorption characteristics of the myoglobin, the meat surfaces becoming a darker red (Winkler, 1939). Such meat will also appear dark because its surface will not scatter light to the same extent as will the more "open" surface of meat of lower ultimate pH (Lawrie and Ledward, 2006). As expected, in the present study (Table 6), pH_{24h} was significantly negatively correlated with L^* value (r=–0.55, P<0.05) and significantly positively correlated with visual colour score (r=0.63, P<0.01) and a^* value (r=0.51, P<0.05). Additionally, a^* value was significantly negatively correlated with visual marbling score (r=–0.66, P<0.01) and L^* value (r=–0.51, P<0.05), and was significantly positively correlated with visual color score (r=0.61, P<0.01) and with b^* value (r=0.64, P<0.01).

Proximate composition: Moisture, protein, total fat and total ash concentrations of all four muscles (PM, SM, LD and TB) from Swallow-Belly Mangulica pigs are presented in Table 4. The LD muscles showed significantly (P<0.01) the lowest moisture concentration (691.6 g/kg) and significantly (P<0.01) the highest total fat concentration (84.3 g/kg), comparing to other three muscles. Moisture concentration in other three muscles (PM, SM and TB) varied between 717.1 and 742.1 g/kg (TB), while total fat concentrations were between 25.5 (SM) and 68.4 g/kg (TB), without significant (P>0.05) differences among these muscles. Protein concentration in all four muscles (PM, SM, LD and TB) varied between 195.0 (TB) and 222.6 ggkg (SM), while total ash concentrations were between 9.7 (TB) and 11.8 g/kg (PM), without significant (P>0.05) differences.

Proximate composition of muscles analyzed in the present study is similar to the values reported in the pork composition tables (Lawrie and Ledward, 2006; Italy – INRAN, 2007 / European Institute of Oncology, 2008; Australia – Greenfield *et al.* 2009; Denmark – National Food Institute, 2009; Finland – National Institute for Health and Welfare, 2009; USA – The US Department of Agriculture's, 2009), especially with those reported by INRAN (2007) for heavy pork. Nevertheless, comparing with the data reported by Lawrie and Ledward (2006) for lean pigs at the age of 6 months, one prominent characteristic of Swallow-Belly Mangulica muscles analyzed in the present study is more than twice higher total fat concentration. Also, our results are in agreement with results reported for autochthonous pigs (Coutron-Gambotti *et al.*, 1999; Cava *et al.*, 2003; Estévez *et al.*, 2003; Peinado *et al.*, 2004; Pugliese *et al.*, 2004, 2005), even though in some cases fat concentration in *M. longissimus dorsi* of autochthonous pigs can reach 10% (Galián *et al.*, 2007, 2009; Poto *et al.*, 2007; Mayoral *et al.*, 1999).

The great increase in intramuscular fat, the lesser increase in total nitrogen and the decrease in moisture with age are evident (Lawrie and Ledward, 2006). As expected, in the present study (Table 6), total fat content was significantly negatively correlated with moisture (r=–0.94, P<0.001) and total ash content (r=–0.59, P<0.01). On the contrary, total ash content was significantly (P<0.05) positively correlated with protein content (r=0.54). Additionally, moisture content was significantly positively (r=0.71, P<0.001) and total fat content significantly negatively (r=–0.62, P<0.01) correlated with visual color score. On the contrary, moisture and total ash content were significantly negatively (r=–0.75 and –0.73; respectively, P<0.001), while total fat content was significantly positively ($r=0.82$, $P<0.001$) correlated with visual marbling score. Moisture content was significantly positively ($r=0.53$, $P<0.05$) and protein content significantly negatively ($r=-0.56$, $P<0.05$) correlated with pH_{24h} value. Protein content had significant ($P<0.05$) and positive correlation coefficient with M/T ratio ($r=0.45$). Furthermore, moisture content was significantly negatively ($r=-0.65$, $P<0.01$) and total fat content significantly positively ($r=0.59$, $P<0.01$) correlated with L^* value. On the contrary, moisture content was significantly positively ($r=0.61$, $P<0.01$) and total fat content significantly negatively ($r=-0.52$, $P<0.05$) correlated with a^* value.

Mineral composition: Mineral (P, K, Na, Mg, Ca, Zn, Fe, Cu and Mn) concentrations of all four muscles (PM, SM, LD and TB) from Swallow-Belly Mangulica pigs are presented in Table 5. The order of the minerals in all four muscles in mg/kg was K>P>Na>Mg>Ca>Zn>Fe>Cu>Mn. Mean concentrations of five minerals including K, Mg, Fe, Cu and Mn were the highest in the PM muscle, while mean concentrations of three minerals including P, Na and Ca were the highest in the SM muscle. Mean concentration of Zn was the highest in the TB muscles. The LD muscles (muscles with the highest total fat concentration) had the lowest mean concentration of all determined minerals, except P. The lowest mean concentration of P was found in TB muscles. According to Greenfield and Southgate (2003), the main source of nutrients variation in animal tissues is the ratio of muscle to fat tissue. Variations in the lean-fat ratio affect the levels of most other nutrients, which are distributed differently in the two fractions.

As shown in Table 5, the concentration of K in all PM, SM, LD and TB muscles was in the range from 3490 (LD) to 4611 mg/kg (PM), with mean of 3931 mg/kg. The minimal and maximal values in all PM, SM, LD and TB muscles for P were 1915 (TB) and 2341 mg/kg (SM), respectively. The mean P concentration in all four muscles was 2091 mg/kg. The lowest, the mean and the highest Na concentration in the PM, SM, LD and TB muscles was 503 (LD), 656 and 885 mg/kg (SM), respectively. Mg concentration in all PM, SM, LD and TB muscles was between 226 (SM) and 261 mg/kg (PM). The mean Mg concentration in all four muscles was 244 mg/kg. The lowest coefficient of variation (4.10%) in all four muscles was found for Mg. Furthermore, the concentration of Ca in all PM, SM, LD and TB muscles was in the range from 48.0 (PM) to 88.2 mg/kg (SM), with mean of 67.6 mg/kg. The minimal and maximal values in all PM, SM, LD and TB muscles for Zn were 18.8 (LD) and 45.4 mg/kg (TB), respectively. The mean Zn concentration in the all four muscles was 28.5 mg/kg. The lowest, the mean and the highest Fe concentration in the PM, SM, LD and TB muscles was 12.0 (LD), 18.5 and 25.9 mg/kg (PM), respectively. Cu concentration in all PM, SM, LD and TB muscles was between 0.75 (LD) and 2.48 mg/kg (PM). The mean Cu concentration in all four muscles was 1.38 mg/kg. The highest coefficient of variation (28.57%) in all four muscles was found for Cu. Finally, the concentration of Mn in all PM, SM, LD and TB muscles was in the range from 0.15 (LD) to 0.26 mg/kg (PM), with mean of 0.20 mg/kg. Although, mineral differences, except K, among PM, SM, LD and TB muscles were significant ($P<0.05$), each individual mineral concentration determined for each muscle analyzed in the present study was in agreement with values reported in the pork composition tables (Lawrie and Ledward, 2006; Tomović *et al.*, 2011 a, 2013 a; Italy – INRAN, 2007 / European Institute of Oncology, 2008; Australia – Greenfield *et al.*, 2009; Denmark – National Food Institute, 2009; Finland – National Institute for Health and Welfare, 2009; USA – The US Department of Agriculture's, 2009). Comparing mineral concentrations of pork from Swallow-Belly Mangulica with Chato Murciano pigs Fe concentration showed approximately two times lower concentration (Galián *et al.*, 2007, 2009; Poto *et al.*, 2007). According to Greenfield and Southgate (2003), amounts of nutrients in animal tissues (meat and edible offal) vary naturally in the range which is not defined.

Table 1. Results of the analytical quality control programme (n = 8) used in the determination of the proximate composition of muscle

Quality control	Moisture	Nitrogen	Fat	Ash
Certified concentration (g/kg)	688±2.6	16.3±0.6	143±5.0	26.5±1.0
Recovery (%)	99.6	100.4	99.7	100.0

Table 2. Sensory characteristics of four muscles from Swallow-Belly Mangulica pigs

Muscle	Colour	Marbling
PM	$5.50±0.42^{aA}$	$1.08±0.13^{cB}$
	(4.5–6.0)	(1.0–1.5)
SM	$4.92±1.10^{aAB}$	$1.76±0.55^{bcB}$
	(3.5–6.0)	(1.5–2.5)
LD	$3.78±0.34^{bB}$	$2.90±0.52^{aA}$
	(3.3–4.5)	(2.0–4.0)
TB	$5.62±0.25^{aA}$	$1.98±0.74^{bAB}$
	(5.0–6.0)	(1.0–3.0)
P value	<0.001	<0.001
All muscles	4.96±0.94	1.93±0.83
	(3.3–6.0)	(1.0–4.0)

^{abc}indicates significant difference within column at $P<0.05$; ^{AB}indicates significant difference within column at $P<0.01$.

In the present study, Mg content was significantly positively correlated with K ($r=0.78$, P<0.001), P (r=0.66, P<0.01), Fe (r=0.60, P<0.01) and Mn (r=0.45, P<0.05) contents (Table 6). Furthermore, Mn content was significantly positively correlated with Zn (r=0.57, P<0.01), Fe (r=0.64, P<0.01) and Cu (r=0.55, P<0.05) contents. P content was significantly (P<0.05) positively correlated with K and Fe contents (r=0.50 and 0.54, respectively). Also, Na content had significant (P<0.01) and positive correlation coefficient with Ca content (r=0.61), as well as, Fe and Cu contents (r=0.62). Additionally, Mg, Zn, Fe and Mn contents were significantly positively correlated with visual color score (r=0.63, P<0.01, r=0.73, P<0.001, r=0.58, P<0.01; r=0.63, P<0.01, respectively). On the contrary, K, P, Mg, Fe and Mn contents were significantly negatively correlated with visual marbling score (r=–0.63, P<0.01; r=–0.71, P<0.001; r=–0.85, P<0.001; r=–0.70, P<0.01; r=–0.55, P<0.05, respectively). Zn and Mn content had significant (P<0.001) and positive correlation coefficient with pH_{24h} value (r=0.73 and 0.61, respectively). Furthermore, Mg, Zn, Fe and Mn contents were significantly negatively correlated with L^* value (r=–0.58, P<0.01; r=–0.67, P<0.01; r=–0.55, P<0.05; r=0.52, P<0.05, respectively). On the contrary, Mg, Zn, Fe, Cu and Mn contents were significantly positively correlated with a^* value (r=0.52, P<0.05; r=0.46, P<0.05; r=0.71, P<0.001; r=0.59, P<0.01; r=0.68, P<0.01, respectively). Na, Mg, Zn, Fe, Cu and Mn contents were significantly positively correlated with moisture content (r=0.47, P<0.05; r=0.71, P<0.001; r=0.52, P<0.05; r=0.60, P<0.01; r=0.49, P<0.05; r=0.67, P<0.01, respectively). P content had significant and positive correlation coefficient with protein content (r=0.63, P<0.01). P, Na, Mg, Fe and Mn contents were significantly negatively correlated with total fat content (r=–0.63, P<0.01; r=–0.48, P<0.05; r=–0.76, P<0.001; r=–0.59, P<0.01; r=–0.56, P<0.05, respectively). On the contrary, K, P and Mg contents were significantly positively correlated with total ash content (r=0.58, P<0.01; r=0.85, P<0.001; r=0.71, P<0.001, respectively).

Table 3. Physical characteristics of four muscles from Swallow-Belly Mangulica pigs

Muscle	pH value		WHC				Colour		
	pH_{30min}	pH_{24h}	M (cm^2)	RZ (cm^2)	M/RZ	M/T	L^* (lightness)	a^* (redness)	b^* (yellowness)
PM	6.23±0.20 (6.02–6.46)	5.63±0.09^{abAB} (5.56–5.78)	4.90±0.59 (4.27–5.87)	6.56±0.56 (5.95–7.17)	0.75±0.05 (0.70–0.82)	0.41±0.02 (0.39–0.45)	38.93±2.38^{bB} (35.25–40.90)	22.88±2.33^{aA} (19.62–24.89)	7.21±2.09 (4.28–9.08)
SM	6.22±0.12 (6.07–6.36)	5.55±0.08^{bcBC} (5.46–5.66)	4.74±0.36 (4.23–5.17)	5.58±1.08 (4.75–7.34)	0.86±0.10 (0.70–0.95)	0.49±0.05 (0.44–0.55)	40.86±5.83^{bAB} (35.15–47.47)	16.59±0.53^{bB} (15.70–16.95)	6.47±1.08 (5.39–7.59)
LD	6.25±0.25 (6.09–6.67)	5.46±0.06^{cC} (5.41–5.56)	4.90±0.50 (4.35–5.50)	5.80±1.15 (4.66–7.33)	0.88±0.25 (0.62–1.18)	0.46±0.07 (0.38–0.54)	46.29±2.00^{aA} (43.64–48.12)	12.79±1.20^{cC} (11.00–14.19)	5.21±0.81 (4.53–6.42)
TB	6.34±0.19 (6.18–6.59)	5.72±0.09^{aA} (5.58–5.81)	5.14±0.35 (4.61–5.55)	6.55±0.43 (5.99–7.13)	0.79±0.06 (0.71–0.88)	0.44±0.02 (0.41–0.47)	38.06±2.35^{bB} (34.24–39.96)	18.80±2.10^{bB} (16.21–21.07)	5.72±1.40 (4.55–7.96)
P value	0.789	<0.001	0.591	0.201	0.410	0.077	0.008	<0.001	0.176
All muscles	6.26±0.19 (6.02–6.67)	5.59±0.12 (5.41–5.81)	4.92±0.45 (4.23–5.87)	6.12±0.91 (4.66–7.34)	0.82±0.14 (0.62–1.18)	0.45±0.05 (0.38–0.55)	41.04±4.59 (34.24–48.12)	17.77±4.06 (11.00–24.89)	6.15±1.52 (4.28–9.08)

^{abc}indicates significant difference within column at P<0.05; ^{ABC}indicates significant difference within column at P<0.01.

Table 4. Proximate composition (g/kg) of four muscles from Swallow-Belly Mangulica pigs

Muscle	Moisture	Protein	Total fat	Total ash
PM	733.9±5.1^{aA} (727.9–742.0)	210.8±4.9 (206.3–217.5)	43.4±3.9^{bB} (39.4–49.0)	11.0±0.8 (10.0–11.8)
SM	734.6±4.6^{aA} (728.6–741.3)	217.0±7.1 (205.8–222.6)	35.7±11.5^{bB} (25.5–54.0)	11.1±0.2 (10.8–11.4)
LD	691.6±13.7^{bB} (673.8–710.9)	212.3±4.9 (203.6–215.1)	84.3±16.0^{aA} (63.1–100.7)	10.4±0.1 (10.3–10.5)
TB	733.5±9.9^{aA} (717.1–742.1)	206.7±7.5 (195.0–213.4)	48.4±12.8^{bB} (36.7–68.4)	10.4±0.7 (9.7–11.4)
P value	<0.001	0.111	<0.001	0.100
All muscles	723.4±20.6 (673.8–742.1)	211.7±6.8 (195.0–222.6)	53.0±22.0 (25.5–100.7)	10.8±0.6 (9.7–11.8)

^{ab}indicates significant difference within column at P<0.05; ^{AB}indicates significant difference within column at P<0.01.

Table 5. Mineral composition (mg/kg) of four muscles from Swallow-Belly Mangulica pigs

Muscle	K	P	Na	Mg	Ca	Zn	Fe	Cu	Mn
PM	4217±322	2168±38^{aA}	613±54^{bB}	251±9^{aA}	59.8±11.1^{bB}	28.9±2.6^{bB}	24.5±1.8^{aA}	1.70±0.45^{a}	0.22±0.02^{aA}
	(3942–4611)	(2116–2206)	(556–669)	(242–261)	(48.0–76.8)	(25.7–32.0)	(21.6–25.9)	(1.30–2.48)	(0.21–0.26)
SM	3804±220	2194±110^{aA}	800±74^{aA}	241±11^{aAB}	82.7±4.6^{aA}	25.1±5.4^{bcB}	19.5±2.9^{bB}	1.43±0.21^{ab}	0.21±0.02^{aA}
	(3513–4051)	(2081–2341)	(733–885)	(226–252)	(78.7–88.2)	(19.8–31.8)	(15.7–22.9)	(1.21–1.65)	(0.19–0.23)
LD	3767±254	2011±53^{bB}	559±52^{bB}	224±10^{bB}	60.0±9.3^{bB}	21.5±2.1^{cB}	13.5±1.3^{cC}	0.98±0.21^{b}	0.17±0.02^{bB}
	(3490–3980)	(1936–2079)	(503–620)	(216–240)	(51.3–71.3)	(18.8–24.4)	(12.0–15.2)	(0.75–1.32)	(0.15–0.20)
TB	3937±325	1977±78^{bB}	651±86^{bB}	242±10^{aAB}	68.1±6.5^{bAB}	38.3±5.2^{aA}	16.4±3.0^{bcBC}	1.40±0.40^{ab}	0.21±0.02^{aA}
	(3518–4255)	(1915–2087)	(557–784)	(233–258)	(59.0–77.1)	(31.9–45.4)	(13.6–21.3)	(0.96–2.06)	(0.19–0.24)
P value	0.089	<0.001	<0.001	0.005	0.001	<0.001	<0.001	0.028	0.002
All muscles	3931±317	2091±121	656±111	244±10	67.6±12.2	28.5±7.4	18.5±4.7	1.38±0.41	0.20±0.03
	(3490–4611)	(1915–2341)	(503–885)	(226–261)	(48.0–88.2)	(18.8–45.4)	(12.0–25.9)	(0.75–2.48)	(0.15–0.26)

^{abc}indicates significant difference within column at P<0.05; ^{ABC}indicates significant difference within column at P<0.01.

Table 6. Overall correlation coefficients (r) among sensory, physical and chemical characteristics

Traits	Marbling	pH_{30min}	pH_{24h}	M	RZ	M/RZ	M/T	L^*	a^*	b^*	Moisture	Protein	Total fat	Total ash
Colour	–0.53*	0.35	0.63**	0.03	0.05	–0.10	–0.02	–0.96***	0.61**	–0.04	0.71***	–0.12	–0.62**	0.25
Marbling		–0.11	–0.19	–0.24	–0.29	0.18	0.09	0.44*	–0.66**	–0.46*	–0.75***	–0.36	0.82***	–0.73***
pH_{30min}			–0.02	0.17	–0.32	0.37	0.30	–0.36	–0.10	–0.33	–0.05	0.09	0.02	0.17
pH_{24h}				–0.05	0.12	–0.21	–0.33	–0.55*	0.51*	0.02	0.53*	–0.56*	–0.31	–0.16
M					0.19	0.38	0.36	0.08	0.11	0.26	–0.04	0.06	0.02	0.07
RZ						–0.83***	–0.68**	0.00	0.40	0.12	0.26	–0.12	–0.20	0.21
M/RZ							0.83***	0.12	–0.37	0.01	–0.35	0.16	0.27	–0.17
M/T								–0.01	–0.38	0.01	–0.16	0.45*	0.00	0.01
L^*									–0.51*	0.15	–0.65**	0.03	0.59**	–0.17
a^*										0.64**	0.61**	–0.16	–0.52*	0.25
b^*											0.26	0.14	–0.29	0.18
Moisture												0.01	–0.94***	0.42
Protein													–0.34	0.54*
Total fat														–0.59**

*indicates significant difference at P<0.05; **indicates significant difference at P<0.01; ***indicates significant difference at P<0.001.

Table 6. Overall correlation coefficients (r) among sensory, physical and chemical characteristics (continued)

Traits	K	P	Na	Mg	Ca	Zn	Fe	Cu	Mn
Colour	0.37	0.11	0.21	0.63**	0.02	0.73***	0.58**	0.44	0.63**
Marbling	–0.63**	–0.71***	–0.15	–0.85***	–0.13	–0.23	–0.70**	–0.35	–0.55*
pH_{30min}	0.26	–0.05	–0.04	0.16	–0.19	0.15	–0.11	–0.11	0.01
pH_{24h}	0.12	–0.23	0.13	0.36	–0.13	0.73***	0.24	0.35	0.61**
M	0.00	–0.05	–0.14	0.08	0.08	0.30	–0.08	0.26	0.08
RZ	0.20	0.03	–0.17	0.28	–0.03	0.25	0.22	0.13	0.37
M/RZ	–0.23	–0.09	0.05	–0.28	0.08	–0.11	–0.28	–0.03	–0.33
M/T	–0.25	0.13	0.21	–0.14	0.37	–0.17	–0.26	–0.09	–0.33
L^*	–0.30	–0.09	–0.24	–0.58**	0.01	–0.67**	–0.55*	–0.36	–0.52*
a^*	0.40	0.24	0.06	0.52*	–0.07	0.46*	0.71***	0.59**	0.68**
b^*	0.12	0.34	0.08	0.14	0.18	–0.08	0.29	0.32	0.22
Moisture	0.37	0.43	0.47*	0.71***	0.35	0.52*	0.60**	0.49*	0.67**
Protein	0.18	0.63**	0.10	0.25	0.27	–0.40	0.07	–0.39	–0.21
Total fat	–0.41	–0.63**	–0.48*	–0.76***	–0.43	–0.35	–0.59**	–0.33	–0.56*
Total ash	0.58**	0.85***	0.01	0.71***	0.22	–0.14	0.43	0.00	0.36
K		0.50*	–0.41	0.78***	–0.28	0.08	0.38	0.01	0.06
P			0.19	0.66**	0.25	–0.35	0.54*	0.13	0.21
Na				–0.01	0.61**	0.15	0.27	0.39	0.43
Mg					0.01	0.30	0.60**	0.20	0.45*
Ca						0.01	0.04	0.11	0.18
Zn							0.26	0.42	0.57**
Fe								0.62**	0.64**
Cu									0.55*

*indicates significant difference at $P<0.05$; **indicates significant difference at $P<0.01$; ***indicates significant difference at $P<0.001$.

Conclusion: The present study provides data on the fresh pork quality from free-range reared Swallow-Belly Mangulica. Many significant differences were found in the mean values of quality traits among four muscles. Mainly, these significant differences could be explained by the variations in the total fat concentration (marbling). With an increase in total fat concentration and visual marbling score, there was a corresponding decrease in redness (a^* value), yellowness (b^* value), moisture, total ash and mineral concentrations, and corresponding increase in lighter color (visual color score and L^* value).

A higher total fat concentration and a darker instrumental colour of muscles are the main characteristics which are in agreement with sensory (visual colour and marbling score) characteristics. Nevertheless, more investigations are needed in order to provide additional information about pork characteristics from free-range reared Swallow-Belly Mangulica pigs specially including eating quality of cooked meat and traditional meat products.

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